

The Bright View of DEL Seen Form LED

James C. Sung^{*,1,2,3}, Juen-Chen Pu³, Sea-Fue Wang³

Address: KINIK Company, 64, Chung-San Rd., Ying-Kuo, Taipei Hsien 239, Taiwan, R.O.C.

Tel: 886-2-2677-5490 ext.1150

Fax: 886-2-8677-2171

e-mail: sung@kinik.com.tw

¹ KINIK Company, 64, Chung-San Rd., Ying-Kuo, Taipei Hsien 239, Taiwan, R.O.C.

² National Taiwan University, Taipei 106, Taiwan, R.O.C.

³ National Taipei University of Technology, Taipei 106, Taiwan, R.O.C.

Keywords: Electroluminescence, Amorphous Diamond, Light Emitting Diode

Abstract

Light emitting diodes (LED) have a bright future as their electro-optical efficiencies are now approaching the standard fluorescence light (70 lumens/watt or 10%). However, LED's costs are still prohibitive (\$20/1000 lumens) in many applications so they cannot replace fluorescence light (\$0.5/1000 lumens) in general. This is particularly true for the applications in back lighting that is indispensable for electronics with LCD for monitors of computer, television, scanner, PDA and the like. The backing lighting is now dominated by cold cathode fluorescence light (CCFL). For paneled lighting, the costly LEDs have other handicaps, such as their inability to diffuse light to a larger area, and their mixing colors (RGB) do not match with eye sensitivities that are tuned to more natural white light.

In terms of panel lighting, electro luminescence (EL) has intrinsic advantages. Firstly, EL is a two dimensional design that is more compatible with the panel lighting than the complicated structure of LED. Moreover, there is no semiconductor involved in emitting light so the cost is much lower. Furthermore, because the low electrical power is involved, the heat generation is minimal in the lighting device. Consequently, the electro optical efficiency for EL can be higher than LED.

Although EL has a long history tracing back to 1936 when Destriau discovered that ZnS powder dispersed in castor oil could be illuminated by applying an AC electrical field. Since then, EL has been applied to back lighting that is relatively dim. There are two major obstacles that EL has not overcome, viz., the high voltage required to trigger the illumination, and the rapid decay of the luminosity with time. These two problems are now solved with the use of amorphous diamond as the electrode and the replacement of AlN as the phosphor. Amorphous diamond can dramatically reduce the voltage required for illumination; and AlN significantly boost the stability of the phosphor.

Amorphous diamond (tetrahedral amorphous carbon or tac) contains carbon atoms with mostly in distorted diamond bonding (sp³). It has the highest atomic density (>176 nm⁻³ for diamond) of all materials (e.g. four times higher than most closest packed metals). Because each atom is unique in the distortion of tetrahedral bonds, there are numerous discrete energy levels for electrons to perch on. Amorphous diamond has the highest entropies of all materials in both atomic configuration and electronic configuration, as such it is uniquely capable to allow electrons to increase energy by receiving incremental energies that exceed the energy difference among various electronic states. For example, amorphous diamond can allow valence electrons to climb up the energy ladder with thermal agitation so electrons can emit in vacuum or in a dielectric material. In contrast, electrons in an insulator (e.g. diamond) will not be disturbed by weak phonons due to the wide energy gap between valence band and conduction band; whereas electrons in a conductor (e.g. graphite) cannot accumulate phonon energy due to the overlapping of conduction band and valence band.

Two ITO (indium tin oxide) coated glass of the common LCD panels were used to construct a Diamond EL or DEL. One of them is coated on the ITO with copper doped ZnS as the phosphor; and the other is coated on the ITO with amorphous diamond. The two panels are glued together by epoxy with a total gap between them of about 60 microns. It was observed that the effective turn-on voltage for the panel was reduced by coating with amorphous diamond from 80 V to 40 V. Moreover, the input voltage could be reduced to only 3V by converting the DC field into AC of 3500 Hz.

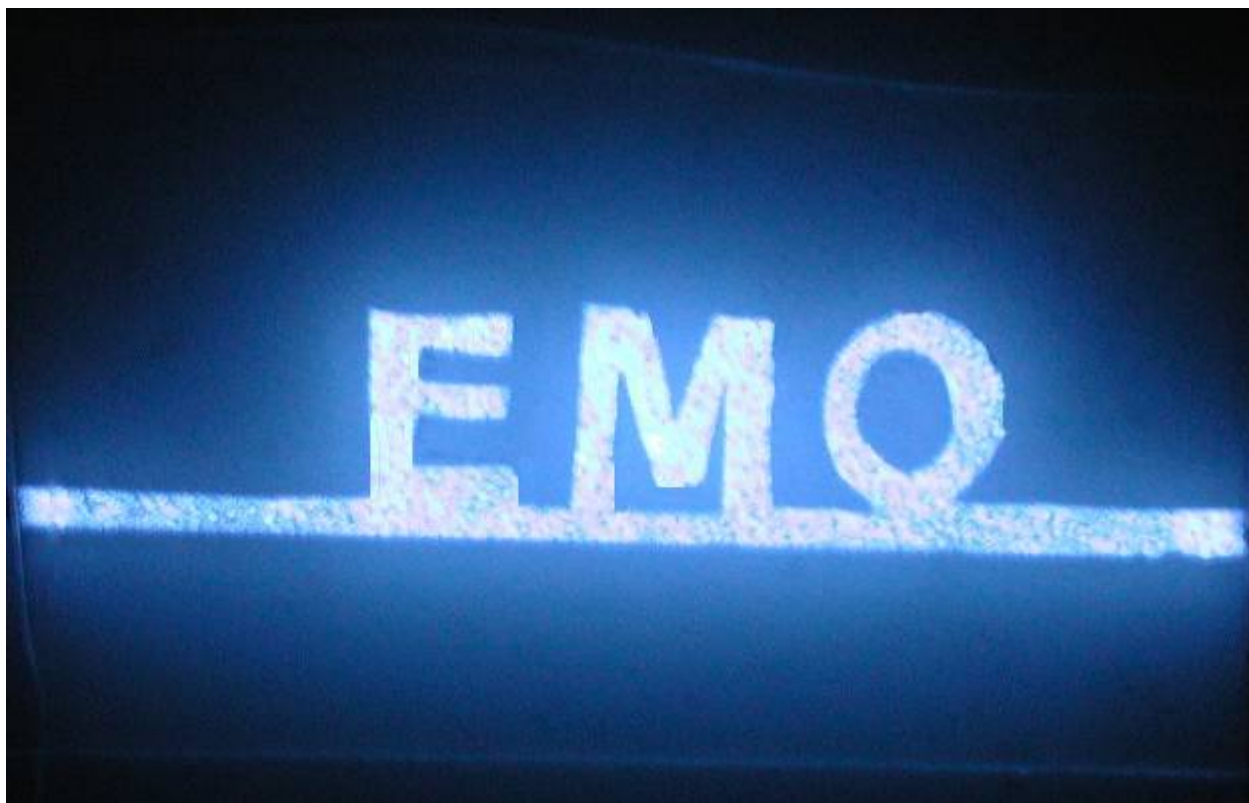


Fig.1: The DEL display with the input of 3V at 3500 Hz. EMO stands for electro-magnetic-optical research lab at Taipei University of Technology.

Although DEL may be used to generate bright light with high energy efficiency, its decay rate of luminosity must be reduced. One problem of the decay is caused by the irreversible diffusion of the activator atoms (e.g. Cu) in the phosphor layer, particularly along the grain boundaries of the carrier (e.g. ZnS) particles. This diffusion is triggered by the local heating due to the concentration of electrical current through the low resistance path. One way to overcome this problem is to disperse the electrical path by using phosphors of nano sized particles. The phosphor layer must be heat treated beforehand to assure the thermal stability of the host structure (e.g. the reduction of defect concentration by annealing) and the dopant substitutions (e.g. in the tetrahedral coordinated positions).

Another way to improve the reliability of the DEL is to use dielectric materials (e.g. PZT) to sandwich the phosphor layer. In this case, the phosphor layer is separated from the electrodes so electrons can flow more uniformly in the phosphor layer to avoid local heating.

The best method to stabilize the phosphor layer is to use AlN as the host material. AlN is with the wurtzite structure that is isostructural to ZnS. AlN is much more compact in atomic packing and it is significantly more thermally stable. During the processing of AlN (e.g. in making AlN heat spreader for laser diode), oxygen is inevitably incorporated (e.g. by adding yttrium oxide as a sintering additive). The oxygen substitution of nitrogen in AlN will give luminescence at about 380 nm and this peak position is relatively fixed when the oxygen content is higher than 0.7 wt%. Moreover, if AlN is doped with Mn (e.g. 0.1-1 wt%), a red luminescence peak is observed for Mn^{4+} around 600 nm; and another green one is formed with Mn^{++} ions in AlN. If Eu is used as the dopant, a green luminescence peak around 2.4 eV (green) is formed.

If AlN phosphor with the right dopant (e.g. Mn, Eu, Sm...) is used, the DEL can be much more thermally stable so the decay rate of luminosity can be greatly slowed down. Moreover, AlN phosphor can be combined with ZnS or oxide phosphor to produced a mixed spectrum of luminescence. These different phosphor layers may also be combined to become a composite material for multiple luminescence with different triggers such as by moving electrons, as well as UV radiation from other phosphor layers.